Energy and Economic Impacts of U.S. Federal Energy and Water Conservation Standards Adopted From 1987 Through 2020

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Abstract

This paper presents estimates of the key impacts of U.S. national energy and water conservation standards adopted from 1987 through 2020. The standards for consumer products, commercial and industrial equipment, lighting products, and plumbing products include those set by legislation as well as standards adopted by the Department of Energy (DOE) through rulemaking.

In 2020, the standards saved an estimated 5.4 quads of primary energy, which is equivalent to 5.4% of total U.S. energy consumption, and 1.9 trillion gallons of water, which is equivalent to approximately 13% of the annual water withdrawals from the public supply in the U.S. The estimated reduction in CO_2 emissions associated with the standards in 2020 was 251 million metric tons, which is equivalent to 5.5% of total U.S. CO_2 emissions. The annual savings in operating costs for households and businesses totaled $83.8 billion, and the average household saved $508 in operating costs as a result of standards on residential appliances and plumbing products.

The estimated cumulative past and future energy and water savings from these standards amount to 231.6 quads of energy and 50 trillion gallons of water. The estimated cumulative CO_2 emissions reduction from the standards come to 10 billion metric tons. Accounting for the increased upfront costs of more-efficient products and the energy and water cost savings over the products' lifetime, the standards have a cumulative net present value of benefit of $2,138 billion using 3 percent discount rate and $2,197 billion using 7 percent discount rate.

Introduction

The U.S. Federal energy conservation program for consumer products and certain commercial and industrial products was established by the Energy Policy and Conservation Act of 1975 (EPCA). EPCA established a program consisting of test procedures, labeling, and energy conservation targets for 19 types of consumer products. The National Energy Conservation Policy Act of 1978 amended EPCA by replacing the energy conservation targets program and directing that energy conservation standards be set for the covered consumer products. With the passage of the National Appliance Energy Conservation Act in 1987 (NAECA 1987), EPCA was further amended to establish the first national energy conservation standards for consumer products. Subsequent amendments in the National Appliance Energy Conservation Act of 1988 (NAECA 1988), the Energy Policy Act of 1992 (EPACT 1992), the Energy Policy Act of 2005 (EPACT 1992), and the Energy Independence and Security Act of 2007 (EISA 2007) further expanded the scope of coverage to include additional consumer products, certain commercial and industrial equipment, lighting products, as well as water conservation standards for residential and commercial products.

EPCA, as amended, requires the Department of Energy (DOE) to update or establish standards at levels that "achieve the maximum improvement in energy [or water] efficiency … which the Secretary determines is technologically feasible and economically justified." EPCA defines "economically justified" standards as those for which benefits exceed the costs, given a number of factors, including impacts on consumers and manufacturers and the nation's need to save energy or water.

This report presents estimates of the key impacts of the energy and water conservation standards that have been adopted from 1987 through 2020.[1] It updates the results presented in Meyers et al.,[1] which covered standards adopted through 2015. The standards covered include those set by legislation as well as standards adopted by DOE through rulemaking. The estimates cover both historic and projected impacts of these standards. The impacts include primary (or full-fuel-cycle) energy savings and water savings, net present value of consumer[2] benefits, and reductions in CO_2 emissions.

Table 1 lists products covered by standards, the initial year(s) compliance was or will be required, and the legislation that initially authorized each standard. The standards that were issued in <u>2016-2020</u> cover the following products (compliance year in parentheses):[3]

- Battery chargers (2018)
- Dehumidifiers (2019)

[1] In this report, "adopted" means either issued by DOE or passed into law by Congress.
[2] The term "consumer" as used in this report refers to all buyers and users of appliances and equipment covered by standards.
[3] The products in italics were issued by DOE in 2016 but not published until January 2020. The compliance year is based on publication of the final rule.

- Miscellaneous residential refrigeration products (2019)
- Ceiling fans (2020)
- Walk-in coolers and freezers (2020)[4]
- Pool pumps (a sub-category of pumps) (2021)
- *Uninterrupted power supplies (a sub-category of external power supplies) (2022)*
- Residential central air conditioners and heat pumps (2023)
- *Commercial packaged boilers (2023)*
- *Commercial air compressors (2025)*
- *Portable air conditioners (2025)*

In addition, in 2019 DOE issued a final determination for general service incandescent lamps (GSILs) clarifying that the January 1, 2020 backstop for general service lamps from EISA 2007 had not been triggered, which impacted the previous savings estimate for GSILs.

Table 1. Federal Energy and Water Conservation Standards for Appliances and Equipment Adopted From 1987 Through 2020

Product	**Compliance Date for Original Standard and Updates**	**Authorizing Legislation**
RESIDENTIAL		
Clothes Washers[1]	1988, 1994, 2004/2007, 2015/2018	NAECA 1987
Clothes Dryers	1988, 1994, 2014	NAECA 1987
Dishwashers[1]	1988, 1994, 2010, 2013	NAECA 1987
Refrigerators and Refrigerator-Freezers	1990, 1993, 2001, 2014	NAECA 1987
Freezers	1990, 1993, 2001, 2014	NAECA 1987
Room Air Conditioners	1990, 2000, 2014	NAECA 1987
Central Air Conditioners and Heat Pumps	1992/1993, 2006, 2015, 2023	NAECA 1987
Water Heaters	1990, 2004, 2015	NAECA 1987
Furnaces	1992, 2013	NAECA 1987
Boilers	1992, 2012, 2020	NAECA 1987
Direct Heating Equipment	1990, 2013, 2021	NAECA 1987
Cooking Products	1990, 2012	NAECA 1987
Pool Heaters	1990, 2013	NAECA 1987
Ceiling Fans	2007, 2020	EPACT 2005
Torchieres	2006	EPACT 2005
Dehumidifiers	2007, 2012, 2019	EPACT 2005
External Power Supplies	2008, 2016, 2022	EISA 2007
Microwave Oven Standby Power	2016	EISA 2007
Battery Chargers	2018	EISA 2007
Furnace Fans	2019	EISA 2007
Misc. Residential Refrigeration Products	2019	EPCA[2]

[4] DOE adopted standards for product classes that were included in the remand of the 2014 rule for this equipment.

Portable Air Conditioners	2025	EPCA[2]
COMMERCIAL & INDUSTRIAL		
Warm Air Furnaces	1994, 2023	EPACT 1992
Packaged Boilers	1994, 2023	EPACT 1992
Air Conditioners and Heat Pumps	1994/1995, 2003/2004, 2010, 2012, 2012-14, 2018/2023	EPACT 1992
Water Heaters, Hot Water Supply Boilers and Unfired Hot Water Storage Tanks	1994, 2004	EPACT 1992
Electric Motors	1997, 2010, 2016	EPACT 1992
Distribution Transformers	2007, 2010, 2016	EPACT 1992, EPACT 2005
Clothes Washers[1]	2007, 2018	EPACT 2005
Unit Heaters	2008	EPACT 2005
Walk-in Coolers and Walk-in Freezers	2009, 2017, 2020	EISA 2007
Refrigerators, Refrigerator-Freezers and Freezers	2010, 2012, 2017	EPACT 2005
Automatic Ice Makers	2010, 2017	EPACT 2005
Refrigerated Beverage Vending Machines	2012, 2019	EPACT 2005
Pumps	2019, 2021	EPACT 1992[3]
Commercial Air Compressors	2025	EPACT 1992
LIGHTING PRODUCTS		
Fluorescent Lamp Ballasts	1990, 2005/2010, 2014	NAECA 1988
General Service Fluorescent Lamps and Incandescent Reflector Lamps	1995, 2008, 2012, 2017	EPACT 1992, EISA 2007
Medium Base Compact Fluorescent Lamps	2006	EPACT 2005
Illuminated Exit Signs	2006	EPACT 2005
Traffic Signal Modules and Pedestrian Modules	2006	EPACT 2005
Ceiling Fan Light Kits	2007, 2020	EPACT 2005
Mercury Vapor Lamp Ballasts	2008	EPACT 2005
Metal Halide Lamp Ballasts and Fixtures	2009, 2017	EISA 2007
General Service Incandescent Lamps,[4] Intermediate Base Incandescent Lamps and Candelabra Base Incandescent Lamps	2012/2014	EISA 2007
PLUMBING PRODUCTS		
Faucets[5]	1994	EPACT 1992
Showerheads[5]	1994	EPACT 1992
Water Closets (Toilets)	1994/1997	EPACT 1992
Urinals	1994/1997	EPACT 1992
Pre-rinse Spray Valves[5]	2007, 2019	EPACT 2005

1. Water and energy conservation standard
2. EPCA gave DOE the authority to include new products as covered products.
3. EPACT 1992 gave DOE the authority to include new equipment as covered equipment.
4. In 2019 DOE issued a final rule in which it withdrew the revised definitions of general service lamp and general service incandescent lamp established in the January 2017 definition final rules.
5. Water conservation standard, but also saves energy used for hot water.

Updates for this Report

The results presented in this report reflect the following updates to the data:

- Historic energy prices include data through 2020.
- Projected energy prices reflect projections in the *Annual Energy Outlook 2021* (*AEO 2021*).
- Carbon dioxide (CO_2) emissions factors for the electric power sector include data through 2020.
- Projected CO_2 emissions factors for the electric power sector reflect projections in *AEO 2021*.
- Estimates of water savings from plumbing product standards established by EPACT 1992 were revised to incorporate improved base case assumptions.
- Historic and projected water prices were updated to reflect national survey data for 2020 and more recent data for the Water Consumer Price Index.

Analysis Method Overview

Different analytical methods were used for five sets of standards. For NAECA 1987 and NAECA 1988 standards and DOE updates of those standards issued before 2007, we utilized the analyses conducted by Lawrence Berkeley National Laboratory (LBNL) in 2007-2008.[2] For EPACT 1992 standards, we developed new estimates for this study. For EPACT 2005 standards, we reviewed and utilized an analysis conducted by Nadel *et al.*[3] and added information from DOE analyses where available. For most of the EISA 2007 standards, we drew upon an analysis conducted by DOE.[4] For the other EISA 2007 standards,[5] we used unpublished national impact analyses that were prepared by LBNL. For standards issued by DOE in 2007-2020, we drew on the national impact analyses performed for the rulemakings for each of the standards and adapted the results for the framework of this study. Appendix A further describes the use of the above sources in this study.

It is important to note that the analyses performed for the rulemakings for each of the standards issued by DOE in 2007-2020 were highly detailed and were carefully reviewed by stakeholders. All of the other sources used for this study were much less detailed in their approach and less extensively reviewed.

The most challenging aspect of estimating the impacts of standards is characterizing what would have happened without new or amended standards. We call this counterfactual against which impacts of standards is measured the "base case." The sources used for this study vary in how they characterized the base case. The LBNL analysis of the NAECA standards and DOE updates of those standards before 2007 estimated a dynamic base case in which the energy efficiency of

[5] Dishwashers, residential boilers, dehumidifiers, and GSILs.

the products improves somewhat even without standards. The analyses performed for DOE's rulemakings also consider how the efficiency might change in the absence of new or amended standards. In contrast, the analyses used for EPACT 1992, EPACT 2005, and EISA 2007 standards used simple assumptions (in many cases, no change in efficiency) regarding the base case. Thus, the energy savings estimated for these standards may overstate the actual savings.

We focused on three key impacts associated with standards: (1) primary or full-fuel-cycle energy savings; (2) additional installed costs; and (3) operating cost savings. Beginning with standards adopted in 2009, the savings are in terms of full-fuel-cycle (FFC) energy use, which includes the energy consumed in extracting, processing, and transporting primary fuels (i.e., coal, natural gas, petroleum fuels), and thus presents a more complete picture of the impacts of energy conservation standards.

Operating cost savings primarily consist of energy cost savings. Energy cost savings were estimated using various combinations of historical national-average annual energy prices and price projections in the analyses for the first four sets of standards. These were then adjusted (scaled) using historical national-average annual energy prices by sector through 2020, and the latest Energy Information Administration (EIA) long-term projections of average annual energy prices after 2020. For standards issued by DOE in 2007-2020, we initially used the energy cost savings estimated for each rulemaking, but we then scaled the savings to reflect actual historical national-average annual energy prices through 2020, and the latest projections of average annual energy prices for years after 2020.

For standards that save water,[6] we also included water cost savings where possible. The energy savings estimated for many of these standards reflect reductions in use of hot water

In some cases (primarily the DOE rulemakings in 2007-2020), the operating cost savings also include any changes in maintenance and repair costs associated with the standards.

We also estimated annual reductions in CO_2 emissions based on the electricity savings and natural gas savings associated with the standards. For the present report, we developed national-average marginal CO_2 emissions factors for the electricity generation sector (historic and projected) based on data published by the EIA and marginal emissions factors developed by the Energy Efficiency Standards Department. See Appendix A for further discussion. We then paired these factors with the annual primary or FFC energy savings for the electricity generation sector from the standards.

For each standard we developed a time series of annual impacts, with economic impacts expressed in constant dollars. For the NAECA standards and DOE updates of those standards before 2007, and for standards issued by DOE in 2007-2020, we followed DOE's convention and

[6] These include standards on dishwashers and clothes washers as well as plumbing product standards.

estimated annual impacts for each standard for 30 years worth of shipments. For most of the other standards, for which the base case often assumed no change in efficiency, we used a shorter period of shipments as a way of compensating for the lack of a dynamic base case, which might tend to overstate the savings from standards. For all standards, we estimated annual energy savings and operating cost savings until products installed in the final year of shipments are retired from the stock. Retirement is based on the average lifetime for each product.

Using the annual operating cost savings and installed costs, we derived a net present value (NPV) by discounting future impacts to the present (defined as 2020 for this report). For economic impacts occurring after 2020, we used discount rates of 3% and 7%, which are the rates used by DOE in its analyses of national impacts, in accordance with guidance from the Office of Management and Budget to Federal agencies on the development of regulatory analysis.[5] For economic impacts occurring before 2020, we derived estimates of their present value using interest rates of 3% and 7%. This approach reflects the view that the present value of the past stream of benefits should reflect the returns to those "profits" had they been invested elsewhere in the economy. We also present results without applying interest rates to past benefits.

Product-Level Impact of Standards: The Case of Refrigerator-Freezers

Figure 1 illustrates how standards have had an important effect on the energy efficiency of new products, in this case refrigerator-freezers. The average new refrigerator-freezer in 2010 used only 44% of the energy per year as an average new unit in 1985. Total energy use for these products has declined even as shipments increased and the average size of new units grew. Nationally, in 2010 refrigerator-freezers used one-third less total energy than in 1985 even though there were 70 million more units in use.[7]

[7] The increase in total energy use depicted after 2025 is due to growth in purchases of refrigerator-freezers. If the standard is updated as required by EPCA, the declining trend would continue.

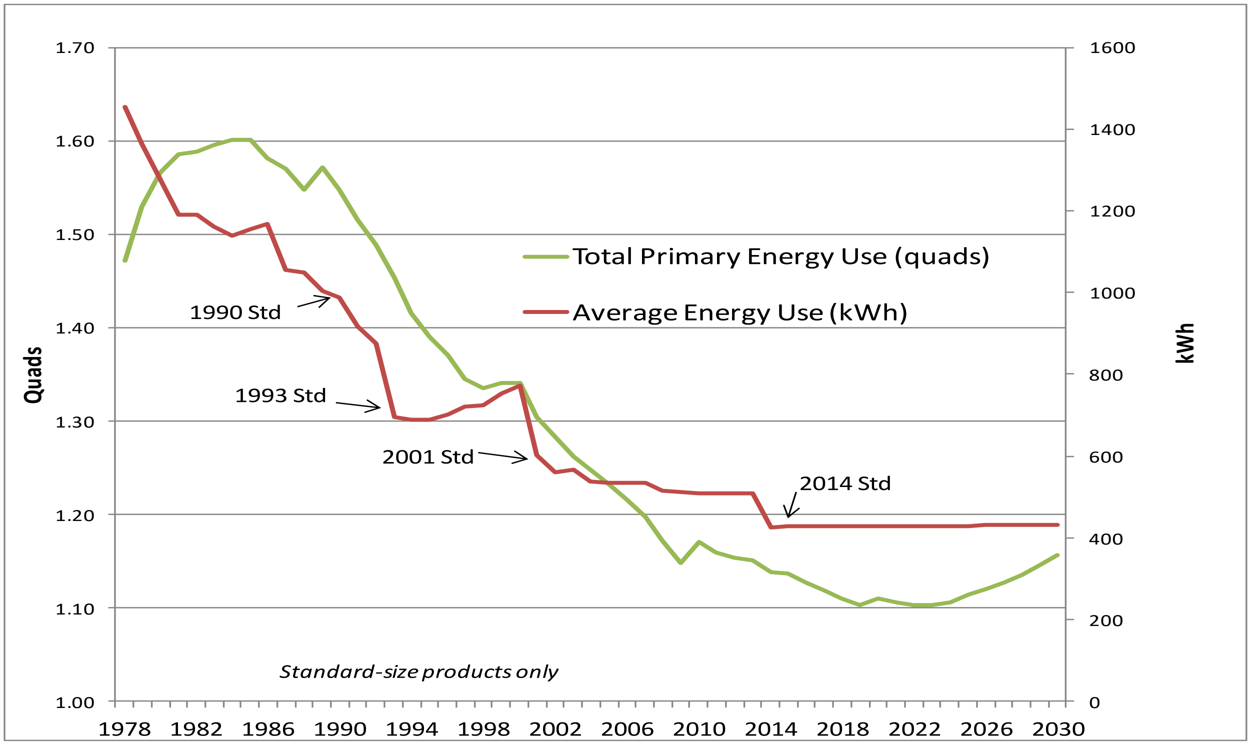

Figure 1. Refrigerator-Freezer Energy Use Trends: Average Energy Use for New Products and Total Energy Use for Refrigerator-Freezers
Source: AHAM Fact Books and 2011 DOE standards rulemaking for residential refrigeration products.[8]

National Impacts[9]

In 2020, the energy and water conservation standards saved an estimated 5.4 quads of primary energy, which is equivalent to 5.3% of total U.S. energy consumption. The savings in operating costs totaled $83.8 billion.[10]

As shown in Table 2, the cumulative primary energy savings through 2020 amount to 70.8 quads. Residential sector standards account for 63 percent of the total energy savings (and most of the energy savings from standards on plumbing products are in homes).

[8] http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/refrig_finalrule_tsd.pdf
[9] Additional results, including impacts by each standard, are available upon request from the authors.
[10] All monetary values reported are in 2020 dollars unless noted otherwise.

Over the entire time period considered (1990-2090),[11] the cumulative primary energy savings amount to 231.6 quads (Table 3). Residential product standards account for more than half of the total cumulative primary energy savings.[12]

The cumulative energy savings achieved through 2020 are only 31 percent of the total cumulative energy savings. Thus, most of the savings from standards already adopted will occur in the future.

Table 2. Cumulative Primary/FFC Energy Savings Through 2020 for Federal Standards

Product sector	Primary/FFC energy savings (quads)	Share of energy savings
Residential*	44.5	63%
Commercial & Industrial**	20.7	29%
Plumbing Products	5.5	8%
Total	70.8	100%

* Includes lighting products in residential application.
** Includes lighting products in commercial and industrial application.

Table 3. Cumulative Primary/FFC Energy Savings for Federal Standards (1990-2090)

Product sector	Cumulative energy savings (quads)	Share of total cumulative energy savings
Residential*	125.9	54%
Commercial & Industrial**	98.9	43%
Plumbing Products	6.9	3%
Total	231.6	100%

* Includes lighting products in residential application.
** Includes lighting products in commercial and industrial application.

Over the entire time period considered, the cumulative consumer NPV associated with the standards is $2,197 billion at 7% discount/interest rate and $2,138 billion at 3% discount/interest rate (Table 4 and Table 5). In addition to energy cost savings from energy conservation

[11] Most of the savings occur well before 2090. For recently-adopted standards, 30 years of shipments ends around 2050, but some of the products sold in 2050 may last two decades or more.
[12] The results for residential products includes impacts from lighting product standards that are estimated to occur in homes. Similarly, the results for commercial and industrial products includes impacts from lighting product standards that are estimated to occur in the commercial and industrial sectors.

standards, the consumer NPV includes water cost savings from those standards that affect both energy and water use (such as standards on clothes washers), as well as energy cost savings from water conservation standards that save hot water (i.e., standards on faucets and showerheads).

Table 4. Cumulative Consumer Costs and Benefits for Federal Standards (1990-2090), 7% discount rate

Product sector	Present Value of Additional First Cost (billion $)	Present Value of Operating Cost Savings (billion $)	Net Present Value (billion $)	Share of Net Present Value (%)
Residential*	$653	$1,757	$1,104	50%
Commercial & Industrial**	$218	$747	$529	24%
Plumbing Products	-	$564	$564	26%
Total	$871	$3,068	$2,197	100%

* Includes lighting products in residential application.
** Includes lighting products in commercial and industrial application.

Table 5. Cumulative Consumer Costs and Benefits for Federal Standards (1990-2090), 3% discount rate

Product sector	Present Value of Additional First Cost (billion $)	Present Value of Operating Cost Savings (billion $)	Net Present Value (billion $)	Share of Net Present Value (%)
Residential*	$549	$1,699	$1,151	54%
Commercial & Industrial**	$215	$801	$586	27%
Plumbing Products	-	$402	$402	19%
Total	$764	$2,902	$2,138	100%

* Includes lighting products in residential application.
** Includes lighting products in commercial and industrial application.

Table 6 presents the annual and cumulative water savings from standards, which include water savings from water conservation standards as well as from energy conservation standards that also save water (such as standards on clothes washers and dishwashers).[13] In 2020, standards saved an estimated 1.9 trillion gallons of water, which is equivalent to approximately 13% of the

[13] Note that water savings estimates are not available for standards on commercial plumbing products (water closets, urinals, and faucets).

water withdrawals from the public supply in the U.S. The estimated dollar savings from reduced water use in 2020 amounted to $12.2 billon.

Table 6. Annual and Cumulative Water Savings for All Water-Conserving Standards

	(trillion gallons)	
	Annual	**Cumulative through**
2020	1.9	25.6
2030	1.4	42.2
2040	.37	49.5
2050	0.005	50.5

As shown in Table 7, the estimated reduction in CO_2 emissions associated with the standards in 2020 was 251 million metric tons, which amounts to 5% of total U.S. energy-related CO_2 emissions in 2020.

Table 7. Annual and Cumulative Reduction in Carbon Dioxide Emissions for All Energy Conservation Standards

	(million tons CO_2)	
	Annual	**Cumulative through**
2020	251	4,027
2030	232	6,524
2040	155	8,387
2050	70	9,438

Figure 2 shows the annual (primary or FFC energy savings for each sector, and Figure 3 shows the annual undiscounted net consumer impact. The impacts peak in the 2030-2035 period as purchases of products subject to standards increase. The decline in impacts reflects the analytical convention of counting impacts for 25-30 years of shipments for each standard. As current standards are revised and new standards are adopted, the impacts from all standards will likely not decline.

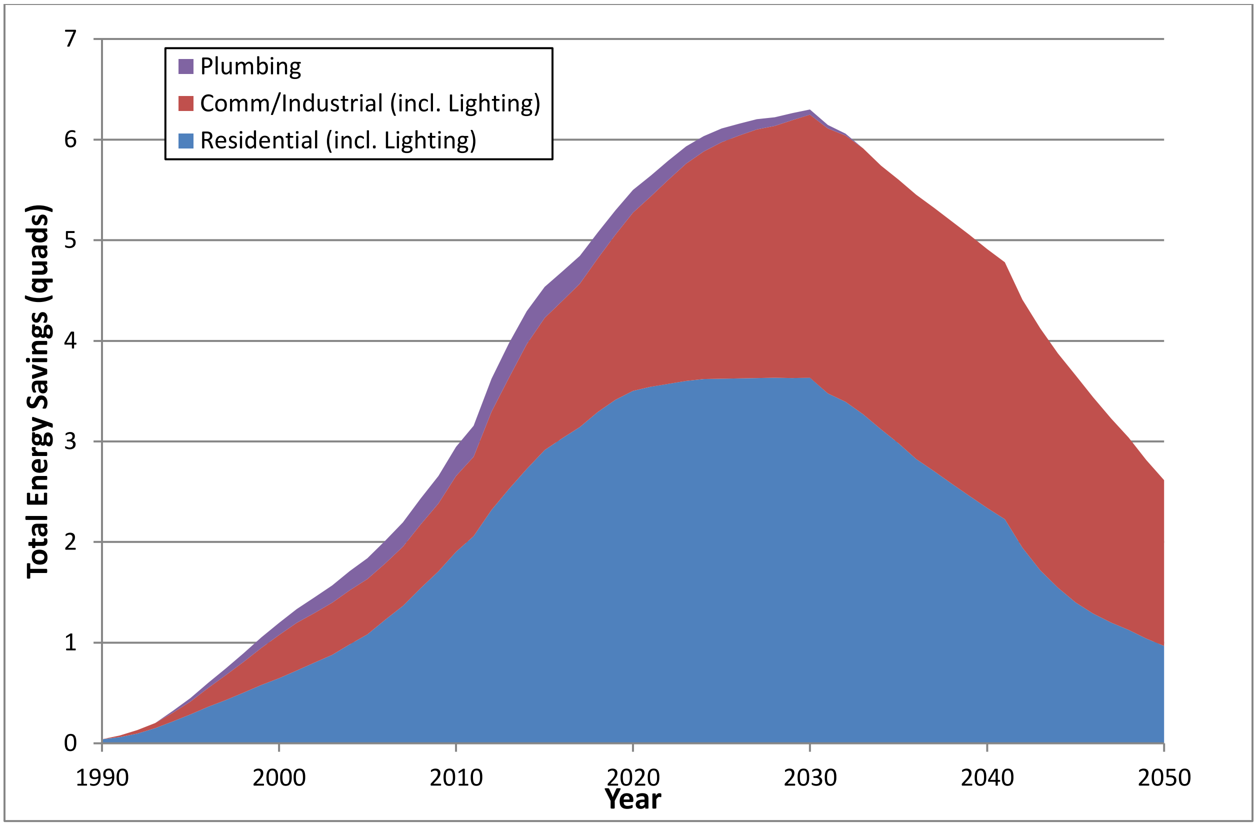

Figure 2. Annual Total Energy Savings for all Standards by Sector

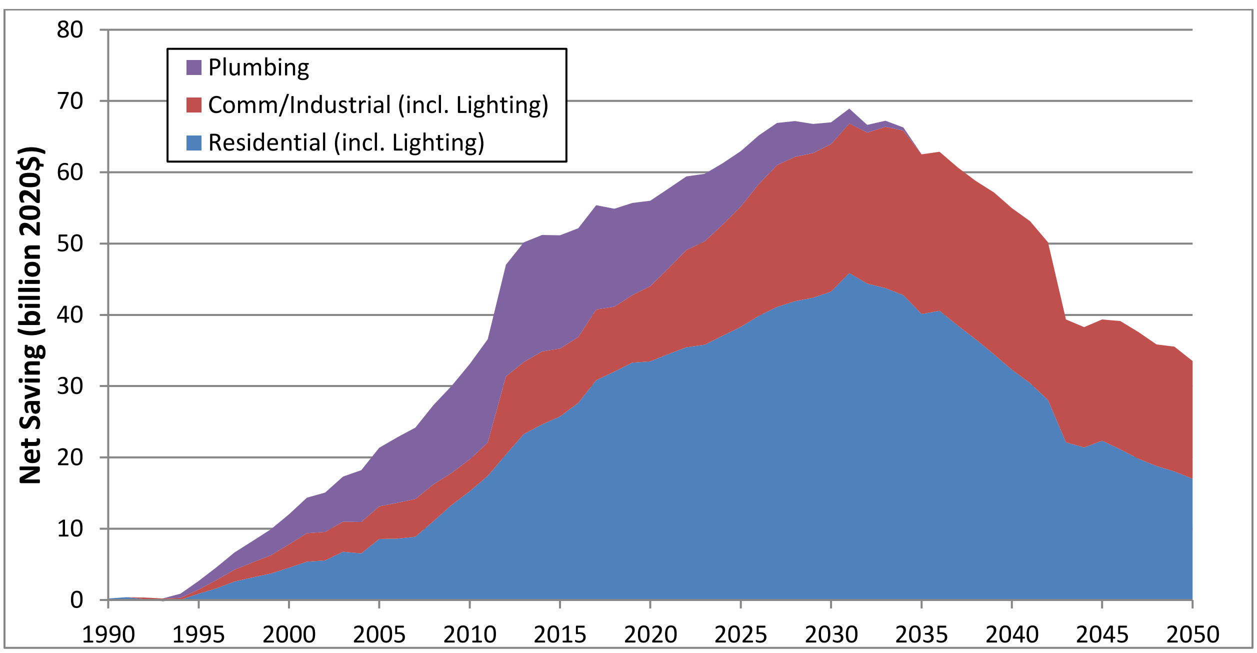

Figure 3. Annual Undiscounted Net Consumer Benefit for all Standards by Sector

Benefits to Households and Businesses

By the end of 2020, the cumulative utility bill savings paid by households and businesses amounted to $1,095 billion. The cumulative savings through 2030 is estimated to be $1,960 billion. Net benefits, which consider the upfront costs paid by households and businesses, are lower than these amounts, but the investments in efficiency will continue to yield benefits over the lifetime of the appliances and equipment.

In 2020, we estimate that the average household saved $508 in operating costs as a result of residential appliance standards (including plumbing products). By now, most U.S. households use one or more appliances that were subject to Federal energy or water conservation standards. On average, the primary energy savings from residential and plumbing standards in 2020 amounted to 29 million Btu per household, which is equivalent to 18 percent of the average total energy use of 162 million Btu per household.

Sources of Uncertainty

A major source of uncertainty is the assumed hypothetical base case against which the impacts of standards are measured. In principle, a base case should reflect how the market for a given product will evolve without the standards under consideration. Estimating the consumer demand for higher efficiency products and the marketing decisions of product manufacturers is difficult. Even more difficult is estimating what other policies, either Federal or State, might be implemented if there were no Federal efficiency standards for a given product. For the standards adopted by DOE since 2008, a good amount of consideration and stakeholder input went into the construction of the base case. For many of the other standards included in this report, the base case reflects simple assumptions.

The time period over which impacts are measured for a given standard is also a source of uncertainty. There is no inherent reason why one should use 30 years of shipments for each standard. The appropriate time period is related to assumptions about the base case and how quickly the market would have reached the efficiency levels in the with-standards case had there not been new or amended standards. In this study, we implicitly "stack" consecutive standards on the same product such that the previous standards still have an impact even after an amended standard has taken effect. The reason for this is that the analysis of each newly amended standard should in principle use a base case that approximates the prior with-standards case. In reality each new analysis uses a base case that is deemed appropriate at that time. Thus, the stacking of new standards on top of previous standards used by our analysis is at best an approximation.

The estimates of per-unit energy savings and additional cost in the sources used for this study are also subject to uncertainty. Most of the sources assume that the incremental costs of higher efficiency remain constant over time.[14] This assumption likely overstates the true costs for two

[14] In 2011 DOE began to account for change in product prices in its forecasts.

reasons. First, manufacturers of appliances and equipment often find ways to reduce the cost of producing higher efficiency products when forced to adapt to standards. Second, inflation-adjusted prices of many types of appliances and equipment have trended downward in recent decades. To the extent that this trend continues, it means that the incremental cost of higher efficiency products may decline over time.

The estimates of primary energy savings in the sources we used are based on estimates of "site" energy savings (i.e., savings where the product is in operation). Most of the older sources we used convert site savings to primary savings using an average multiplier. In contrast, the National Impact Analysis spreadsheets from the DOE rulemakings incorporate marginal site-to-primary energy conversion factors. These factors represent the response of the electricity system to an incremental decrease in consumption associated with appliance standards. DOE uses annual marginal site-to-primary energy conversion factors based on a version of the Energy Information Administration's National Energy Modeling System (NEMS). The marginal factors are lower than average site-to-primary conversion factors and are likely more accurate. If we had been able to apply marginal site-to-source conversion factors to all of the standards included, the estimated primary energy savings would be somewhat lower.

For consumer cost savings that occurred in the past, there is some question as to whether the compounding of past savings used in this study is appropriate. We have not found clear guidance in the literature, but there is some precedent for the practice of compounding past savings to estimate their present value.[15] There is uncertainty regarding the extent to which the savings from appliance standards were invested elsewhere in the economy, and what the appropriate interest rate should be. Without compounding of past savings, the cumulative consumer NPV for all standards adopted through 2020 would be 10 to 32 percent (at 3% and 7% interest rates, respectively) less than reported here.

There is evidence that consumers use higher efficiency appliances more intensively due to the reduction in operating cost. The extent of this so-called direct rebound effect varies among products.[6] In recent years DOE has accounted for a rebound effect in many of its rulemakings. Thus, the energy savings estimates for many standards adopted by DOE since 2008 include an adjustment (subtraction) for a rebound effect.[16] The other sources used for this study do not include such an adjustment. The lack of this adjustment means that the savings from those sources may be overestimated by 5 to 10 percent. We do not attempt to estimate an indirect rebound effect which would reflect the impact of consumer spending of monetary savings from standards.

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[15] See for example: http://www.dalemarsden.ca/docs/publications/Marsden_etal_2006.pdf

[16] DOE does not adjust the energy cost savings for the rebound effect because it believes that, if it were able to monetize the increased value to consumers associated with the rebound effect, this value would be similar to the foregone energy savings.

Conclusion

We estimate that energy and water conservation standards for appliances and equipment issued from 1987 through 2020 have saved a total of 70.8 quads through 2020, an amount equal to 71 percent of total U.S. energy use in 2020, and 25.6 trillion gallons of water, which is nearly twice as much as the annual water withdrawal for public supply in the U.S.

In 2020, the standards saved an estimated 5.4 quads of primary energy, which is equivalent to 5.4% of total U.S. energy consumption, and and 1.9 trillion gallons of water, which is equivalent to approximately 13% of the annual water withdrawals from the public supply in the U.S. The savings in operating costs for households and businesses totaled $83.8 billion, and the average household saved $508 in operating costs as a result of standards on residential appliances and plumbing products. The estimated reduction in CO_2 emissions associated with the standards in 2020 was 251 million metric tons, which is equivalent to 5.5% of total U.S. CO_2 emissions.

The majority of the savings attributable to the standards adopted thus far are still to come, as products subject to the standards enter the stock. The estimated cumulative past and future energy and water savings from these standards amount to 231.6 quads of energy and 50 trillion gallons of water. The estimated cumulative CO_2 emissions reduction from the standards come to 10 billion metric tons. Accounting for the increased upfront costs of more-efficient products and the energy and water cost savings over the products' lifetime, the standards have a cumulative net present value of benefit of $2,138 billion using 3 percent discount rate and $2,197 billion using 7 percent discount rate.

Appendix A: Methods for Estimating National Impacts from Standards

General Methods

The energy cost savings were first taken from each of the sources described in the sections below. These sources used combinations of historic energy price data and forecasts from specific versions of EIA's *Annual Energy Outlook (AEO).* We adjusted the original energy cost savings estimates using actual average annual energy prices by sector through 2020 and recently-projected average annual energy prices after 2020. The historical prices were taken from DOE Energy Information Administration (EIA) sources. The projected prices are based on EIA's *Annual Energy Outlook 2021 (AEO 2021).*[7] The method involved scaling the original energy cost savings estimates using multipliers that relate the historical energy prices and the energy prices in the most recent *AEO* to the same-year values that were used in the original source, after expressing both in same-year dollars. We converted dollars from the year used in the various sources to 2020$ using the GDP implicit price deflator.

Water cost savings are calculated using estimates of water savings from various sources described below and a time series of national-average marginal water prices. The time series is anchored by survey data for 2020 collected for a current dishwasher standards rulemaking. Historic prices before 2020 were estimated using the Water consumer price index, adjusted for inflation using the GDP implicit price deflator. Future prices after 2020 are based on a linear fit of the historic adjusted Water CPI.

The reductions in CO_2 emissions related to electricity savings are calculated using annual marginal CO_2 emissions factors (CO_2 per quad of primary energy used for electricity generation) for the electricity generation sector. Marginal emissions factors (for primary energy and FFC energy) for the period 2022-2050 were derived by the LBNL Energy Efficiency Standards group based on the *AEO 2021* Reference case. The primary energy factors were applied for standards for which the energy savings are in primary energy, and the FFC energy factors were applied for standards for which the energy savings are in FFC energy. Values for 2010-2021 were scaled from the 2022 value based on the trend in those years for average electricity generation sector CO_2 emissions factors that we derived from EIA data. For years prior to 2010, we simply applied the 2010 value to be conservative.[17] For years after 2050, we derived values based on the trend in 2040-2050.

NAECA 1987 and 1988 Standards and DOE Updates before 2007

For all of the standards except one, we used the data developed by Meyers *et al*.[1] That study developed a spreadsheet accounting model to calculate energy savings and consumer costs and savings for each product. The model tracks the energy use of products sold in each year,

[17] If we had estimated pre-2010 values based on the trend in average CO_2 emissions factors, the values would be higher than the ones we used.

beginning in the late 1980s. The model uses historic and projected data on annual shipments of each product and subtracts units from the stock using a retirement function based on the estimated average lifetime of each product.

The key feature of the model is that it associates a specific average energy consumption and average product price for each vintage of a given product. (A vintage refers to the products shipped in a given year.) Both of these variables are a function of the energy efficiency assigned to each vintage. In most cases, the actual energy efficiency for each vintage of a product is assigned based on industry sources.

The approach for estimating the impacts of standards involves deriving a base case scenario for average energy efficiency and product price that assumes no standards were or will be implemented. In principle, the base case assumes energy efficiency increases over time as a result of all factors that shape energy efficiency other than Federal standards. For further discussion, see section 2 of Meyers *et al*. (2008).

For the commercial heating, air conditioning, and water heating standards with compliance dates of 2003 and 2004, we started from the following data reported by Belzer and Winiarski:[8] (1) primary energy savings cumulative through 2030 and (2) net economic impacts at a 7-percent discount rate cumulative from units shipped through 2030. We used an average lifetime for these products of 15 years. We assume that units retire uniformly over the lifetime and that the annual energy savings will go up after the effective date until it stabilizes when all the pre-standard units have been replaced by units meeting the standards. This period that it takes for the annual energy savings to reach its maximum is equal to the lifetime of the product. Using these assumptions, we calculate the annual site and primary energy savings that will match the given cumulative energy savings from 2003 to 2030. Then we used the Excel Solver to solve for the unit energy saving and incremental equipment cost per unit that will give a net present value (NPV) that closely matches the given NPV at a 7-percent discount rate. We then extended the time series to include shipments through 2032 to yield a 30-year analysis period.

EPACT 1992 Standards

We developed new estimates for this study, as described below. We assumed no change in base case efficiency over time. To compensate for potential overstatement of savings due to this assumption, we counted impacts for only 20 years worth of product shipments. Further details may be found in spreadsheets that are available from the authors.

Commercial furnaces and boilers, air conditioners and heat pumps, and water heaters

We modified the analytical structure and some of the data developed by Rosenquist et al. for the 2004 study for the National Commission on Energy Policy (NCEP).[9]

We estimated base case efficiencies and unit incremental costs for these products using PNNL (2000). This report presents average efficiencies in 1999 and costs for both an EPACT 1992 baseline product and an average product in 1999. We applied these differentials to derive an approximate pre-EPACT 1992 baseline efficiency and contractor cost for each product.

Electric motors

We developed a simplified NIA model to estimate the impacts of the EPACT 1992 standards for electric motors, using one "average motor" as the basis for the calculations.

The "average motor" energy use was calculated in the base case and in the standards case, using market-weighted averages across the covered horsepower (hp) ranges, pole configurations, and enclosure type to determine the following parameters: operating hours, load, lifetime, horsepower, and efficiency. All inputs were derived from the draft preliminary analysis from DOE's 2011 rulemaking for electric motors.

The base-case efficiency is estimated assuming 30% of shipped motors are at pre-EPACT standard efficiency levels, 30% are already at the EPACT 1992 efficiency levels, and 40% are at National Electrical Manufacturers Association (NEMA) premium efficiency levels. The standards-case efficiency is estimated using a "roll-up" scenario, which leads to assuming 60% of motors are at the EPACT 1992 efficiency levels and 40% are at the NEMA premium efficiency levels.

Motor equipment costs (includes the repair costs) for the "average motor" in the base case and standards case were estimated by extrapolating price and weight data from the preliminary analysis. Repairs are assumed to occur after 5 years of usage and once in a motor's lifetime.

Shipment data were obtained from the preliminary analysis and are assumed to be the same in the base-case and in the standards-case. The market-weighted average lifetime (12 years) was used to calculate the affected stock.

National site energy savings were obtained from multiplying the affected stock by the difference in energy use between the base case and standards case for the "average motor". National equipment incremental costs were calculated using the affected stock multiplied by the difference in equipment costs between the base case and standards case for the "average motor".

Fluorescent lamps and incandescent reflector lamps

<u>Fluorescent lamps</u>

We calculated savings for full-wattage T12 lamps covered by the standards sold after the effective dates of the standards: April 30, 1994 for 8-foot T12 and 8-foot T12/HO lamps and October 31, 1995 for 4-foot lamps. To calculate fluorescent lamp shipments, we adapted the spreadsheet used to analyze the impacts of the NAECA fluorescent ballast standards by Meyers *et al*. The base-case forecast assumed that 60 percent of lamp shipments in 1994 were full-wattage lamps, while 40 percent were reduced-wattage lamps already complying with the EPAct 1992 standards, according to a 1989 report on Massachusetts' lamp standards by Nadel et al.[10]

Since the lamps covered by the EPAct 1992 lamp standards ("covered lamps") were used with magnetic ballasts, and very few T12 lamps used electronic ballasts, we assumed that lamp shipments tracked the pattern of magnetic ballast shipments. When the fluorescent ballast standards came into effect in 2005 for ballasts in new luminaires, there was a corresponding substantial decrease in T12 lamp shipments. By 2010, when the ballast standards took effect for the renovation market as well, very few T12 lamps were sold.

The shipments of covered fluorescent lamps for 1994 were based on estimates by Geller and Nadel.[11] For 1995 - 2010 we scaled this 1994 shipment value to decline according to the annual decrease in magnetic ballast shipments projected in the NAECA ballast standards analysis. Beginning in 2011 we made the simplifying assumption that T12 lamp shipments ceased.

Assumptions for unit wattage savings, product service lifetime, operating hours, and market shares by lamp type and by new vs. renovation market are from DOE's 2000 fluorescent lamp ballast standards analysis. Lamp prices are from the 1992 Lighting Policy Analysis by Atkinson *et al.*[12]

<u>Incandescent reflector lamps</u>

We estimated the impacts of the incandescent reflector lamp standards from 1996 – 2015. (The standards took effect on November 1, 1995, so we assumed that savings began in 1996.) We used shipments data from past and recent analyses to estimate the annual shipments of lamps complying with the standards. For the commercial sector, complying shipments were derived for 1996 - 2000 from the 1992 Lighting Policy Analysis (Atkinson *et al.*), for 2006 - 2015 from DOE's 2009 incandescent reflector lamp standards NIA spreadsheet (DOE 2009),[18] and for 2001 – 2005 by linear interpolation. For the residential sector, we estimated complying shipments for 1995 as 10 percent of total shipments, for 2001 – 2015 from DOE 2009, and for 1996 to 2000 by linear interpolation.

Assumptions for unit wattage savings are from Atkinson *et al.* Product service lifetime and operating hours are from DOE 2009. Lamp prices are from Atkinson *et al.*

Plumbing products

For showerheads, faucets, and toilets, we started with data on product lifetime, product saturations, and water savings in standards and base case from Koomey *et al.*[13] We developed a simple stock accounting model to track the uptake of products at standard-level and baseline efficiency beginning in the compliance year (1994). We assumed that products installed in the base case would gradually rise to the standard levels in a linear manner over a 20-year period.

[18] See: http://www1.eere.energy.gov/buildings/appliance_standards/residential/incandescent_lamps_standards_final_rule_tools.html

We derived water cost savings by applying annual time series of national-average marginal water prices to the estimated site water savings. We dervived energy cost savings from reduced use of hot water in showerheads and faucets applying annual time series of national-average energy prices to the estimated site energy savings.

We estimated that there is zero unit incremental cost for these products because when manufacturers first started to comply with EPACT 1992, they generally did not make significant changes to the products.

The estimates only cover residential use because no data were available to estimate commercial sector impacts of the standards (except for pre-rinse spray valves).

EPACT 2005 Standards

For all of the standards except commercial air conditioners (AC) and heat pumps, we started from the following data reported by Nadel *et al.*[3] for each standard: (1) site energy savings in 2020 and 2030, (2) cumulative energy savings through 2030, (3) NPV for products sold through 2030, (4) lifetime, (5) unit annual energy saving, and (6) unit incremental equipment cost. Nadel *et al.* used a constant efficiency base case, but they also did not model any increase in shipments; these two factors would counteract to some extent.

From the energy savings for 2020 and 2030, we estimated both the site and source energy savings for 25 years of shipments starting from the compliance year. Using the energy savings per unit and the annual energy savings, we calculated the shipments in each year. Once we derived the shipments, we could calculate the total incremental equipment cost.

We accounted for impacts to shipments through 2030. The number of years of shipments ranges from 21 to 25, depending on the particular standard.

For commercial AC and heat pumps, DOE National Impact Analysis spreadsheets were available. For these products, we followed the methods described in the DOE Standards 2007-2010 section.

EISA 2007 Standards

For most EISA 2007 standards, we started from the following data for each product reported by DOE in its technical report:[4] (1) cumulative energy savings (through 2038), (2) NPV at 3-percent and 7-percent discount rates. From other relevant DOE sources, we obtained the lifetimes of the products. The DOE report used a constant efficiency base case, which may tend to somewhat overestimate the savings from the standards. To compensate, we used 25 years of shipments instead of 30 years.

We assumed that units retire uniformly over the lifetime and that the annual energy savings will go up after the compliance date until it stabilizes when all the pre-standard units have been replaced by units meeting the standards. The period that it takes for the annual energy savings to reach its maximum is equal to the lifetime of the product. Using these assumptions, we calculated the annual site and source energy savings that will match the given cumulative energy savings. Then we used the Excel Solver to solve for the unit energy savings and incremental equipment cost per unit that will give an NPV that closely matches the given NPV at a 7-percent discount rate. We then adjusted the calculations to account for 25 years of shipments.

General service incandescent lamps

For general service incandescent lamps, an update was made to previous estimates (i.e., Meyers, et. al 2015). To estimate the impact from the 2012 and 2014 GSIL standards (excluding impacts from a 2020 backstop that DOE determined was not triggered), a simple turnover model was used that did not attempt to account for either shifts in the market efficiency distribution that would have occurred in the absence of standards or standards-induced shifts to lamps more efficient than those required by the standard. Shipments were projected from 2012-2041, initialized from historical shipments from DOE's 2019 GSIL final determination,[19] and were assumed to go to the residential sector. Other parameters came from the 2019 GSIL final determination and the 2014 LBNL report "The evolving price of household LED lamps: Recent trends and historical comparisons for the US market."[14]

Residential boilers, dishwashers, and dehumidifiers

For a few EISA 2007 standards (residential boilers, dishwashers, and dehumidifiers), National Impact Analysis spreadsheets were available. For these products, we followed the approach described in the following DOE Standards section.

DOE Standards 2007-2020

We used the Final Rule national impact analysis spreadsheets from the DOE rulemakings for each of these standards.[20] We set up the spreadsheets for the compliance year and standard levels that were selected in the Final Rules. This gave the annual time series for primary energy savings, additional installed cost, and operating cost savings. In some cases, the time series presented in the spreadsheets were by individual product classes, so we summed them to arrive at totals for the product category or categories in question. In some cases we also made modifications to the spreadsheets to arrive at consistent results across products—for instance, always using 30 years of shipments and extending energy cost savings and energy savings to the end of the lifetime of the units shipped in the 30th year.

[19] https://www.regulations.gov/document?D=EERE-2019-BT-STD-0022-0120
[20] The NIA spreadsheets and associated documentation may be found under the product name at the DOE Appliance and Equipment Standards web site: http://energy.gov/eere/buildings/standards-and-test-procedures.

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